Chapter 6
Processes to Significantly Reduce Pathogens (PSRPs)

6.1 Introduction

Processes to Significantly Reduce Pathogens (PSRPs) are listed in Appendix B of Part 503. There are five PSRPs: aerobic and anaerobic digestion, air drying, composting, and lime stabilization. Under Part 503.32(b)(3), sewage sludge meeting the requirements of these processes is considered to be Class B with respect to pathogens (see Section 5.3). When operated under the conditions specified in Appendix B, PSRPs reduce fecal coliform densities to less than 2 million CFU or MPN per gram of total solids (dry weight basis) and reduce *Salmonella* sp. and enteric virus densities in sewage sludge by approximately a factor of 10 (Farrell, et al., 1985).

This level of pathogen reduction is required, as a minimum, by the Part 503 regulation if the sewage sludge is applied to agricultural land, a public contact site, a forest, or a reclamation site or placed on a surface disposal site[1]. Because Class B biosolids may contain some pathogens, land application of Class B biosolids is allowed only if crop harvesting, animal grazing, and public access are limited for specific periods of time following application of Class B biosolids so that pathogens can be further reduced by environmental factors (see Section 5.5).

The PSRPs listed in Part 503 are essentially identical to the PSRPs that were listed under the 40 CFR Part 257 regulation, except that all requirements related solely to reduction of vector attraction have been removed. Vector attraction reduction is now covered under separate requirements (see Chapter 8) that include some of the requirements that were part of the PSRP requirements under Part 257, as well as some new options for demonstrating vector attraction reduction. These new options provide greater flexibility to the regulated community in meeting the vector attraction reduction requirements.

Although theoretically two or more PSRP processes, each of which fails to meet its specified requirements, could be combined and effectively reduce pathogens (i.e. partial treatment in digestion followed by partial treatment by air drying) it cannot be assumed that the pathogen reduction contribution of each of the operations will result in the 2-log reduction in fecal coliform necessary to define the combination as a PSRP. Therefore, to comply with Class B pathogen requirements, one of the PSRP processes must be conducted as outlined in this chapter, or fecal coliform testing must be conducted in compliance with Class B Alternative 1. The biosolids preparer also has the option of applying for PSRP equivalency for the combination of processes. Achieving PSRP equivalency enables the preparer to stop monitoring for fecal coliform density.

This chapter provides detailed descriptions of the PSRPs listed in Appendix B. Since the conditions for the PSRPs, particularly aerobic and anaerobic digestion, are designed to meet pathogen reduction requirements, they are not necessarily the same conditions as those traditionally recommended by environmental engineering texts and manuals.

6.2 Aerobic Digestion

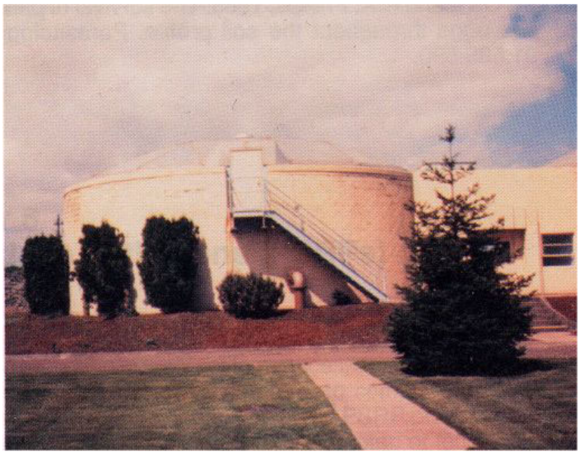
In aerobic digestion, sewage sludge is biochemically oxidized by bacteria in an open or enclosed vessel (see photo). To supply these aerobic microorganisms with enough oxygen, either the sewage sludge must be agitated by a mixer, or air must be forcibly injected (Figure 6-1). Under proper operating conditions, the volatile solids in sewage sludge are converted to carbon dioxide, water, and nitrate nitrogen.

Aerobic systems operate in either batch or continuous mode. In batch mode, the tank is filled with untreated sewage sludge and aerated for 2 to 3 weeks or longer, depending on the type of sewage sludge, ambient temperature, and average oxygen levels. Following aeration, the stabilized solids are allowed to settle and are then separated from the clarified supernatant. The process is begun again by inoculating a new batch of untreated sewage sludge with some of the solids from the previous batch to supply the necessary biological decomposers. In continuous mode, untreated sewage sludge is fed into the digester once a day or more frequently; thickened, clarified solids are removed at the same rate.

The PSRP description in Part 503 for aerobic digestion is:

- Sewage sludge is agitated with air or oxygen to maintain aerobic conditions for a specific mean cell resi-

[1]Unless the active biosolids surface disposal unit is covered at the end of each operating day, in which case no pathogen requirement applies.



Digester in Vancouver, Washington.

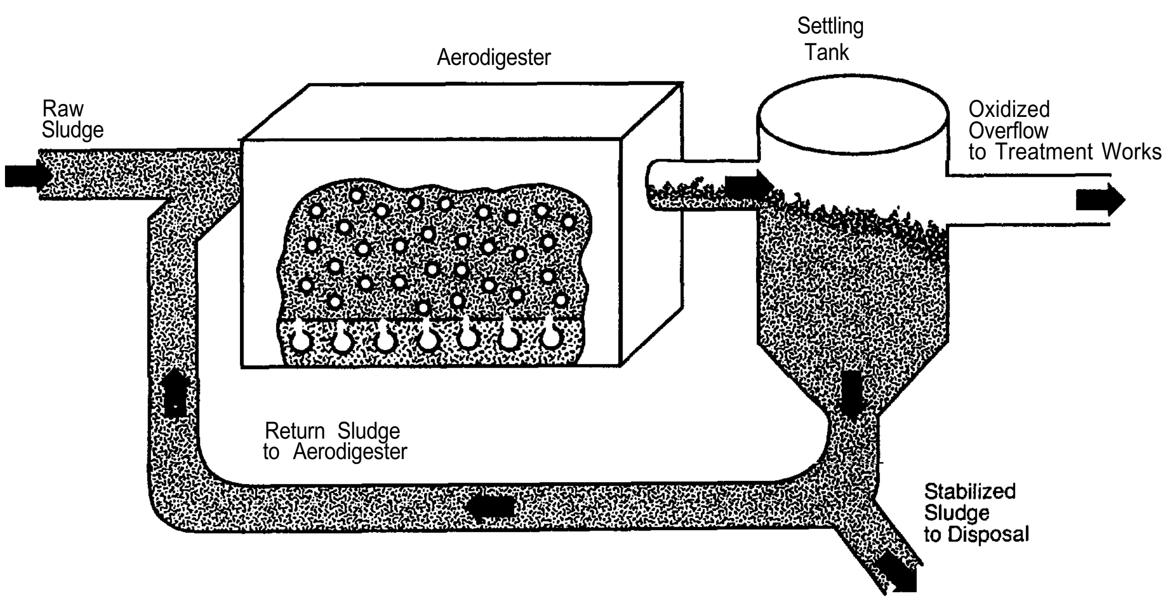


Figure 6-1. Aerobic digestion.

dence time at a specific temperature. Values for the mean cell residence time and temperature shall be between 40 days at 20°C (68°F) and 60 days at 15°C (59°F).

For temperatures between 15°C (59°F) and 20°C (68°F) use the relationship between time and temperature provided below to determine the required mean cell residence time.

$$\frac{\text{Time @T°C}}{40\ \text{d}} = 1.08^{(20-T)}$$

The regulation does not differentiate between batch, intermittently fed, and continuous operation, so any method is acceptable. The mean cell residence time is considered the residence time of the sewage sludge solids. The appropriate method for calculating residence time depends on the type of digester operation used (see Appendix E).

Continuous-Mode, No Supernatant Removal For continuous-mode digesters where no supernatant is removed, nominal residence times may be calculated by dividing liquid volume in the digester by the average daily flow rate in or out of the digester.

Continuous-Mode, Supernatant Removal In systems where the supernatant is removed from the digester and recycled, the output volume of sewage sludge can be much less than the input volume of sewage sludge. For these systems, the flow rate of the sewage sludge out of the digester is used to calculate residence times.

Continuous-Mode Feeding, Batch Removal of Sewage Sludge For some aerobic systems, the digester is initially filled above the diffusers with treated effluent, and sewage sludge is wasted daily into the digester. Periodically, aeration is stopped to allow solids to settle and supernatant to be removed. As the supernatant is drawn off, the solids content in the digester gradually increases. The process is complete when either settling or supernatant removal is inadequate to provide space for the daily sewage sludge wasting requirement, or sufficient time for digestion has been provided. The batch of digested sewage sludge is then removed and the process begun again. If the daily mass of sewage sludge solids introduced has been constant, nominal residence time is one-half the total time from initial charge to final withdrawal of the digested sewage sludge.

Batch or Staged Reactor Mode A batch reactor or two or more completely-mixed reactors in series are more effective in reducing pathogens than is a single well-mixed reactor at the same overall residence time. The residence time required for this type of system to meet pathogen reduction goals may be 30% lower than the residence time required in the PSRP definition for aerobic digestion (see Appendix E). However, since lower residence times would not comply with PSRP conditions required for aerobic digestion in the regulation, approval of the process as a PSRP by the permitting authority would be required.

Other Digesters are frequently operated in unique ways that do not fall into the categories above. Appendix E provides information that should be helpful in developing a calculation procedure for these cases. Aerobic digestion carried out according to the Part 503 requirements typically reduces bacterial organisms by 2-log and viral pathogens by 1-log. Helminth ova are reduced to varying degrees, depending on the hardiness of the individual species. Aerobic digestion typically reduces the volatile solids content (the microbes' food source) of the sewage sludge by 40% to 50%, depending on the conditions maintained in the system.

Vector Attraction Reduction

Vector attraction reduction for aerobically digested sewage sludges is demonstrated either when the percent volatile solids reduction during sewage sludge treatment equals or exceeds 38%, or when the specific oxygen uptake rate (SOUR) at 20°C (68°F) is less than or equal to 1.5 mg of oxygen per hour per gram of total solids, or when additional volatile solids reduction during bench-scale aerobic batch digestion for 30 additional days at 20°C (68°F) is less than 15% (see Chapter 8).

Thermophilic aerobic systems (operating at higher temperatures) capable of producing Class A biosolids are described in Section 7.5.

6.3 Anaerobic Digestion

Anaerobic digestion is a biological process that uses bacteria that function in an oxygen-free environment to convert volatile solids into carbon dioxide, methane, and ammonia. These reactions take place in an enclosed tank (see Figure 6-2) that may or may not be heated. Because the biological activity consumes most of the volatile solids needed for further bacterial growth, microbial activity in the treated sewage sludge is limited. Currently, anaerobic digestion is one of the most widely used treatments for sewage sludge treatment, especially in treatment works with average wastewater flow rates greater than 19,000 cubic meters/day (5 million gallons per day).

Most anaerobic digestion systems are classified as either standard-rate or high-rate systems. Standard-rate systems take place in a simple storage tank with sewage sludge added intermittently. The only agitation that occurs comes from the natural mixing caused by sewage sludge gases rising to the surface. Standard-rate operation can be carried out at ambient temperature, though heat is sometimes added to speed the biological activity.

High-rate systems use a combination of active mixing and carefully controlled, elevated temperature to increase the rate of volatile solids destruction. These systems sometimes use pre-thickened sewage sludge introduced at a uniform rate to maintain constant conditions in the reactor. Operating conditions in high-rate systems foster more efficient sewage sludge digestion.

The PSRP description in Part 503 for anaerobic digestion is:

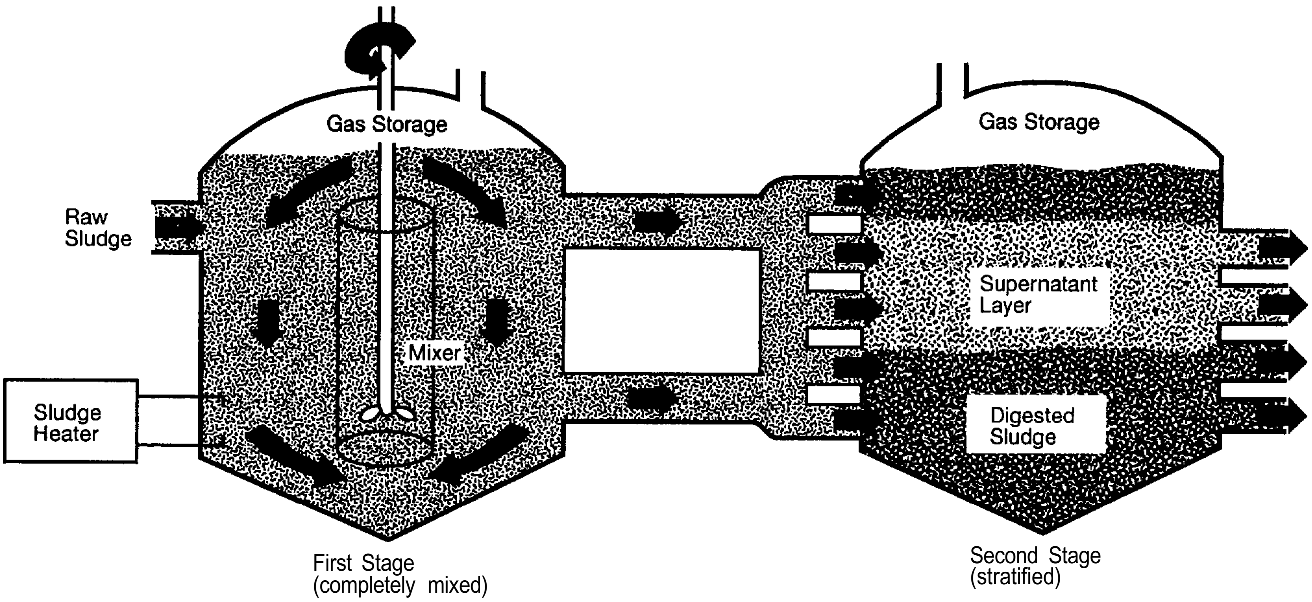


Figure 6-2. Two-stage anaerobic digestion (high rate).

- Sewage sludge is treated in the absence of air for a specific mean cell residence time at a specified temperature. Values for the mean cell residence time and temperature shall be between 15 days at 35°C to 55°C (95°F to 131°F) and 60 days at 20°C (68°F).

Straight-line interpolation to calculate mean cell residence time is allowable when the temperature falls between 35°C and 20°C.

Section 6.2 provides information on calculating residence times. Anaerobic digestion that meets the required residence times and temperatures typically reduces bacterial and viral pathogens by 90% or more. Viable helminth ova are not substantially reduced under mesophilic conditions (32°C to 38°C [90°F to 100°F]) and may not be completely reduced at temperatures between 38°C (100°F) and 50°C (122°F).

Anaerobic systems reduce volatile solids by 35% to 60%, depending on the nature of the sewage sludge and the system's operating conditions. Sewage sludges produced by systems that meet the operating conditions specified under Part 503 will typically have volatile solids reduced by at least 38%, which satisfies vector attraction reduction requirements. Alternatively, vector attraction reduction can be demonstrated by Option 2 of the vector attraction reduction requirements, which requires that additional volatile solids loss during bench-scale anaerobic batch digestion of the sewage sludge for 40 additional days at 30°C to 37°C (86°F to 99°F) be less than 17% (see Section 8.3). The SOUR test is an aerobic test and cannot be used for anaerobically digested sewage sludge.

6.4 Air Drying

Air drying allows partially digested sewage sludge to dry naturally in the open air (see photo). Wet sewage sludge is usually applied to a depth of approximately 23 cm (9 inches) onto sand drying beds, or even deeper on paved or unpaved basins. The sewage sludge is left to drain and dry by evaporation. Sand beds have an underlying drainage system; some type of mechanical mixing or turning is frequently added to paved or unpaved basins. The effectiveness of the air drying process depends very much on the local climate: drying occurs faster and more completely in warm, dry weather, and slower and less completely in cold, wet weather. During the drying/storage period in the bed, the sewage sludge is undergoing physical, chemical, and biological changes. These include biological decomposition of organic material, ammonia production, and desiccation.

Sludge drying operation. (Photo credit: East Bay Municipal Utility District)

The PSRP description in Part 503 for air drying is:

- Sewage sludge is dried on sand beds or on paved or unpaved basins. The sewage sludge dries for a minimum of 3 months. During 2 of the 3 months, the ambient average daily temperature is above 0°C (32°F).

Although not required by the Part 503, it is advisable to ensure that the sewage sludge drying beds are exposed to the atmosphere (i.e., not covered with snow) during the 2 months that the daily temperature is above 0°C (32°F). Also, the sewage sludge should be at least partially digested before air drying. Under these conditions, air drying will reduce the density of pathogenic viruses by 1-log and bacteria by approximately 2-log. Viable helminth ova also are reduced, except for some hardy species that remain substantially unaffected.

Vector Attraction Reduction

Frequently sand-bed drying follows an aerobic or anaerobic digestion process that does not meet the specified process requirements and does not produce 38% volatile solids destruction. However, it may be that the volatile solids reduction produced by the sequential steps of digestion and drying will meet the vector attraction reduction requirement of 38% volatile solids reduction. If this is the case, vector attraction reduction requirements are satisfied.

Example of Meeting PSRP and Vector Attraction Reduction Requirements

Type of Facility	Air Drying
Class	B
Pathogen Reduction	Partially digested sewage sludge is thickened and spread in drying beds. Filling of beds starts in June, and the beds accommodate sewage sludge generated over 1 full year. Beds are then emptied the following September so that all sewage sludge is retained over an entire summer (>0°C ambient temperatures).
Testing	Sewage sludge is tested for pollutants 2 weeks before material is removed and distributed.
Vector Attraction Reduction	Biosolids are land applied and plowed immediately into the soil.
Use or Disposal	Biosolids are delivered to local farmers. Farmers are given information on site restrictions, and must follow harvest, grazing, and public access restrictions.

Vector Attraction Reduction

Air-dried sewage sludge typically is treated by aerobic or anaerobic digestion before it is placed on drying beds. Usually, the easiest vector attraction reduction requirement to meet is a demonstration of 38% reduction in volatile solids (Option 1, See Section 8.2), including the reduction that occurs during its residence on the drying beds.

In dry climates, vector attraction reduction can be achieved by moisture reduction (see Option 7 in Section 8.8, and Option 8 in Section 8.9).

6.5 Composting

Composting involves the aerobic decomposition of organic material using controlled temperature, moisture, and oxygen levels. Several different composting methods are currently in use in the United States. The three most common are windrow, aerated static pile, and within-vessel composting. These are described below.

Composting can yield either Class A or Class B biosolids, depending on the time and temperature variables involved in the operation.

All composting methods rely on the same basic processes. Bulking agents such as wood chips, bark, sawdust, straw, rice hulls, or even-finished compost are added to the sewage sludge to absorb moisture, increase porosity, and add a source of carbon. This mixture is stored (in windrows, static piles, or enclosed tanks) for a period of intensive decomposition, during which temperatures can rise well above 55°C (131°F). Depending on ambient temperatures and the process chosen, the time required to reduce pathogens and produce Class B biosolids can range from 3 to 4 weeks. Aeration and/or frequent mixing or turning are needed to supply oxygen and remove excess heat. Following this active stage, bulking agents may or may not be screened from the completed compost for recycling (see photo), and the composted biosolids are "cured" for an additional period.

Windrow composting involves stacking the sewage sludge/bulking agent mixture into long piles, or windrows, generally 1.5 to 2.7 meters high (5 to 9 feet) and 2.7 to 6.1 meters wide (9 to 20 feet). These rows are regularly turned or mixed with a turning machine or front-end loader to fluff up the material and increase porosity which allows better convective oxygen flow into the material. Turning also breaks up compacted material and reduces the moisture content of the composting media (see photo, next page). Active windrows are typically placed in the open air, except in areas with heavy rainfall. In colder climates, winter weather can significantly increase the amount of time needed to attain temperatures needed for pathogen reduction.

Aerated static pile composting uses forced-air rather than mechanical mixing (see Figure 6-3) to both supply sufficient oxygen for decomposition and carry off moisture. The sewage sludge/bulking agent mixture is placed on top of

Composted sludge is screened to remove the bulking agent prior to land application

Compost mixing equipment turns over a windrow of compost for solar drying prior to screening [Photo credit: East Bay Municipal Utility District)

either (1) a fixed underlying forced aeration system, or (2) a system of perforated piping laid on the composting pad surface and topped with a bed of bulking agent. The entire pile is covered with a layer of cured compost for insulation and odor control. Pumps are used to blow air into the compost pile or suck air through it. The latter provides greater odor control because the compost air can be easily collected and then filtered or scrubbed.

Within-vessel composting systems vary greatly in design, but they share two basic techniques: the process takes place in a reactor vessel where the operating conditions can be carefully controlled (see photo page 49), and active aeration meets the system's high oxygen demand.

Agitated bed systems (one type of within-vessel composting) depend on continuous or periodic mixing within the vessel, followed by a curing period.

Pathogen reduction during composting depends on time and temperature variables (see photo page 49). Part 503 provides the following definition of PSRP requirement for pathogen reduction during composting:

- Using either the within-vessel, static aerated pile, or windrow composting methods, the temperature of the sewage sludge is raised to 40℃ (104°F) or higher and remains at 40℃ (104°F) or higher for 5 days. For 4 hours during the 5-day period, the temperature in the compost pile exceeds 55℃ (131°F).

These conditions, achieved using either within-vessel, aerated static pile, or windrow methods, reduce bacterial pathogens by 2-log and viral pathogens by 1-log.

A process time of only 5 days is not long enough to fully break down the volatile solids in sewage sludge, so the composted sewage sludge produced under these conditions will not be able to meet any of the requirements for reduced vector attraction. In addition, sewage sludge that has been composted for only 5 days may still be odorous. Breakdown of volatile solids may require 14 to 21 days for within-vessel; 21 or more days for aerated static pile; and 30 or more days for windrow composting. Many treatment works allow the finished sewage sludge compost to further mature or cure for at least several weeks following active composting during which time pile turning or active aeration may continue.

Composting is most often used to meet Class A requirements. More guidance for composting operations and how to meet Class A time and temperature requirements is provided in Chapter 7.

Vector Attraction Reduction

Vector attraction reduction must be conducted in accordance with Option 5, or compost must be incorporated into soil when land applied. This option requires aerobic treatment (i.e., composting) of the sewage sludge for at least 14 days at over 40℃ (104°F) with an average temperature of over 45°C (113°F).

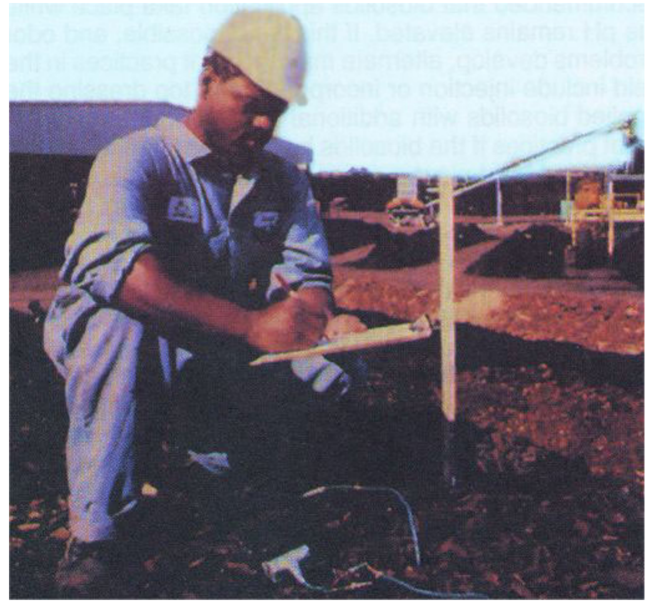
6.6 Lime Stabilization

The lime stabilization process is relatively straightforward: lime — either hydrated lime, $Ca(OH)_2$; quicklime, CaO; or lime containing kiln dust or fly ash — is added to sewage sludge in sufficient quantities to raise the pH above 12 for 2 hours or more after contact, as specified in the Part 503 PSRP description for lime stabilization:

- Sufficient lime is added to the sewage sludge to raise the pH of the sewage sludge to 12 after 2 hours of contact.

For the Class B lime stabilization process, the alkaline material must be a form of lime. Use of other alkaline ma-

Taulman Weiss in-vessel composting facility in Portland, Oregon.



Compost operator measures compost pile temperature as part of process monitorlng. (Photo credit: East Bay Municipal Utility District, Oakland, California)

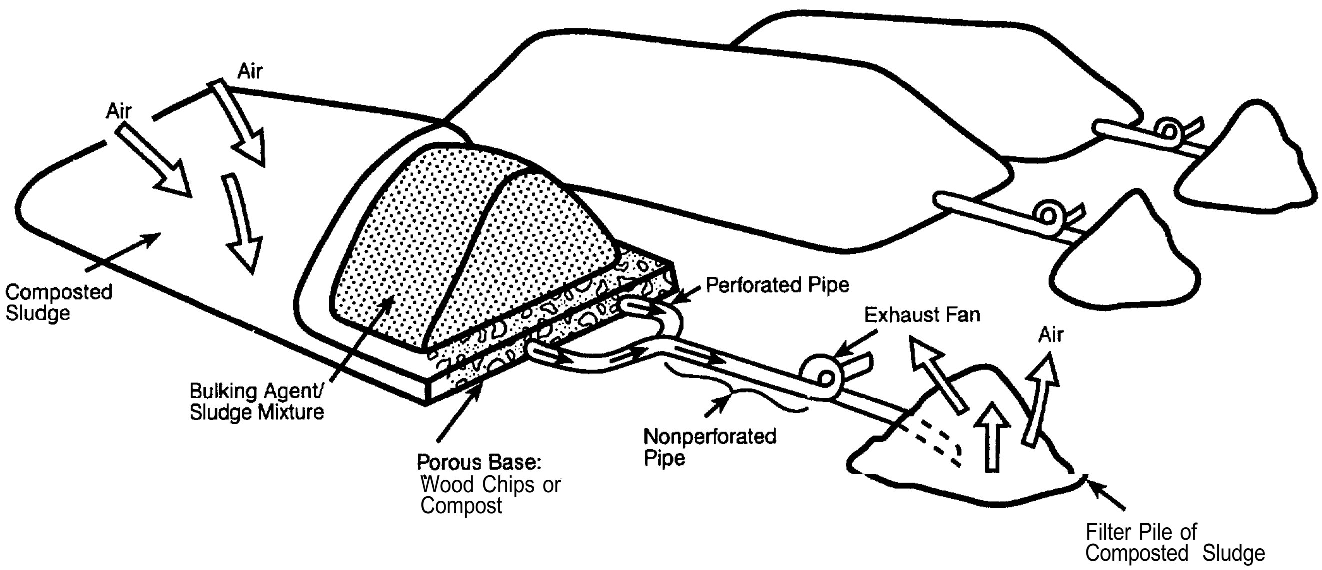


Figure 6-3. Static aerated pile composting.

terials must first be demonstrated to be equivalent to a PSRP. Elevation of pH to 12 for 2 hours is expected to reduce bacterial and viral density effectively.

Lime may be introduced to liquid sewage sludge in a mixing tank or combined with dewatered sewage sludge, providing the mixing is complete and the sewage sludge cake is moist enough to allow aqueous contact between the sewage sludge and lime.

Mixing must be sufficient to ensure that the entire mass of sewage sludge comes into contact with the lime and undergoes the increase in pH and to ensure that samples are representative of the overall mixture (see Chapter 9). pH should be measured at several locations to ensure that the pH is raised throughout the sewage sludge.

A variety of lime stabilization processes are currently in use. The effectiveness of any lime stabilization process for controlling pathogens depends on maintaining the pH at levels that reduce microorganisms in the sewage sludge. Field experience has shown that the application of lime stablized material after the pH has dropped below 10.5 may, in some cases, create odor problems. Therefore it is recommended that biosolids application take place while the pH remains elevated. If this is not possible, and odor problems develop, alternate management practices in the field include injection or incorporation or top dressing the applied biosolids with additional lime. Alternate management practices if the biosolids have not yet left the wastewater treatment plant may include adding additional lime to maintain the elevated pH or additional treatment through drying or composting. Lime stabilization can reduce bacterial and viral pathogens by 99% or more. Such alkaline conditions have little effect on hardy species of helminth ova, however.

Vector Attraction Reduction

For lime-treated sewage sludge, vector attraction reduction is best demonstrated by Option 6 of the vector attraction reduction requirements. This option requires that the sewage sludge pH remain at 12 or higher for at least 2 hours, and then at 11.5 or more for an additional 22 hours (see Section 8.7).

Lime stabilization does not reduce volatile solids. Field experience has shown that the application of lime stabilized material after the pH has dropped below 10.5 may create odor problems. Therefore it is recommended that land application of biosolids take place as soon as possible after vector attraction reduction is completed and while pH remains elevated.

6.7 Equivalent Processes

Table 11.1 in Chapter 11 lists some of the processes that the EPA's Pathogen Equivalency Committee has recommended as being equivalent to PSRP under Part 257. Information on the PEC and how to apply for equivalency are discussed in Chapter 11.

References and Other Resources

Berg, G. and D. Berman. 1980. Destruction by anaerobic mesophilic and thermophilic digestion of viruses and indicator bacteria indigenous to domestic sludges. Appl. Envir. Microbiol. 39(2):361-368.

Farrell, J.B., G. Stern, and A.D. Venosa. 1990. Microbial destructions achieved by full-scale anaerobic digestion. Paper presented at Municipal Wastewater Sludge Disinfection Workshop. Kansas City, MO. Water Pollution Control Federation, October 1995.

U.S. EPA. 1992. Technical support document for reduction of pathogens and vector attraction in sewage sludge. EPA/822/R-93/004.